A SUMMARY OF PYROTECHNIC SHOCK IN THE AEROSPACE INDUSTRY

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Pyrotechnic shock data have been obtained from a survey of the aerospace industry and government agencies. Over 2800 measurements from 30 contributors have been compiled and categorized according to type of pyrotechnic device and structure. These data were analyzed to provide a reference document and establish guidelines for designing and testing to the pyrotechnic shock environment.

This paper presents a summary of the total program and a discussion of pyrotechnic test simulation techniques. Further results from the study, including guidelines for design and for predicting shock environments, are presented in a paper by Dr. Michael B. McGrath, entitled "A Discussion of Pyrotechnic Shock Criteria" during the 41st Shock and Vibration Symposium.

INTRODUCTION

Pyrotechnic shock is perhaps the least understood of the dynamic environments associated with the operation of aerospace vehicles and components. To date, the problem of predicting or even adequately explaining pyrotechnic shock has defied solution by rigorous mathematical treatments. Prediction of the environment and testing techniques are currently based primarily on empirical methods. Recent observations showed that reliable data were widely scattered among many companies and agencies, and that testing technology was not openly discussed between organizations. Therefore, the Goddard Space Flight Center, recognizing that a large amount of data existed in the industry, sponsored a program to collect and categorize these data and establish guidelines for designing structure and equipment to the pyrotechnic shock environment. The study was performed by the Martin Marietta Corporation under Contracts NAS5-15208 and NAS5-21241.

The specific tasks performed in the course of the program were:

A. Compilation of "reduced" pyrotechnic shock data representative of aerospace systems.

B. Definition of distinctive characteristics of pyrotechnic shock transients.

C. Evaluation of the "quality" of typically available pyrotechnic shock data.

D. Recommendation of measurement systems for ground test and flight.

E. Preparation of guidelines defining design information applicable to structure and equipment design.

F. Recommendation of test simulation techniques.

G. Classification of pyrotechnic systems according to the nature of resulting shock and damaging effects.

H. Evaluation of effects of structural configurations and materials on resulting shock characteristics.

I. Formulation of a follow-on research program.

J. Application of shock propagation theory to at least one class of pyrotechnic systems compiled in task G and comparison of results with measured data.

K. Performance of a ground test program using full scale Titan III structure to provide specific information that will aid in the understanding of basic pyrotechnic shock transient phenomena.

L. Investigation of the effects of mass loading on the pyrotechnic shock environment.

A complete description of each of these tasks and the results have been published in a six volume report [1]. This paper presents a brief description of results of selected tasks with emphasis on test simulation of pyrotechnic shock.

DATA COMPILATION AND CATEGORIZATION

Over 2800 pyrotechnic shock measurements were compiled and categorized according to the type of device and type of structure through which the shocks propagated as listed in Table 1. Each measurement is presented in MCR-69-611 [1] showing the acceleration time history, the shock spectrum (using a standard format with an analysis Q of 10 for most cases) and a drawing showing structural configuration including the locations of the pyrotechnic device and the transducers.

Table 1. Outline of Data Classification

A.	Structure cutting charges (mild detonating fuse, flexible linear shaped charge, primachord, etc.)
	1. Skin-ring-frame structure
	2. Truss structure
	3. Other structure
B.	Explosive nuts and bolts
	1. Skin-ring-frame structure
	2. Truss structure
	3. Other structure
C.	Cartridge actuated devices (pin pullers, bolt cutters, cable cutters, etc.)
	1. Skin-ring-frame structure
	2. Truss structure
	3. Other structure
D.	Space Vehicle test data
E.	Flight measurements

CHARACTERISTICS OF PYROTECHNIC SHOCK TRANSIENTS

The compiled pyrotechnic shock data were used to determine distinctive characteristics of the shock transients including propagation velocity, frequency content, and attenuation of amplitude with distance.

The propagation velocity was measured for several different structures. Velocities corresponding to both compressional and shear waves were found to exist in the measured data. Near the shock source, the acceleration time histories are characterized by high amplitude, high frequency complex waves. As the distance between the shock source and the measurement location increases, the high frequency energy is rapidly attenuated, and structural resonances begin to control the shock spectrum. The effect is illustrated by the shock spectra in Fig. 1. It should be recognized that accelerometer installations can seriously influence the measured data, particularly at locations near the shock source. The effect on transducer resonance frequency of several mounting installations has been investigated by Rasanen [2]. This work indicated that the use of aluminum blocks for accelerometer installations could lower the mounted resonance frequency by a factor of 2 to 3 from the transducer resonance specified by the manufacturer.

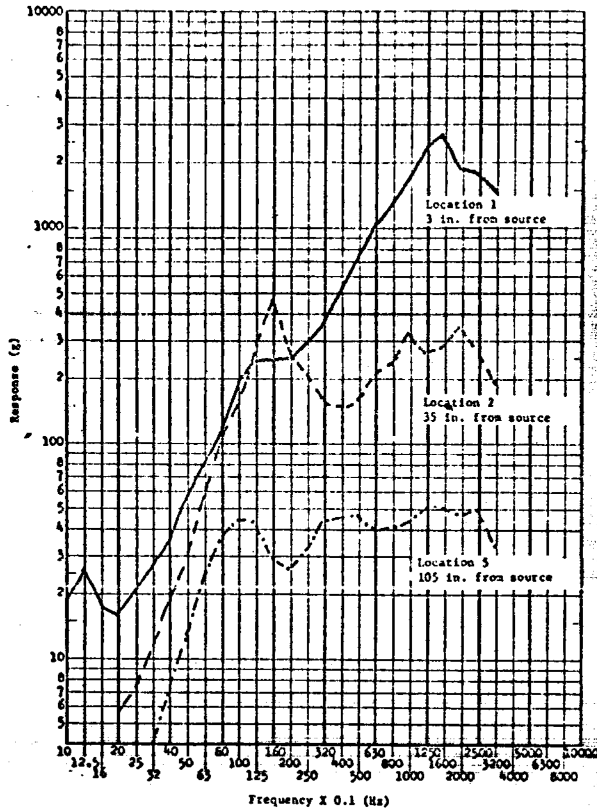

Fig. 1 - Comparison of shock spectra at various propagation distances

DAMAGE EFFECTS

Information concerning damage effects related to shock amplitude is extremely limited because of lack of documented failure histories. One of the perplexing aspects of this study was that in spite of the magnitude of the survey and the response in contribution of data, only 29 miscellaneous anomalies and 17 cases of relay chatter were reported. As a result, methods for relating pyrotechnic shock damage potential with structure and equipment fragility levels do not exist, although some preliminary information indicates shock velocity may be a significant parameter.

Generally, structural failures are confined to small fittings, brackets, bonds, and electrical connectors to small components such as diodes and transistors. Most damage effects are seen in equipment malfunction such as chatter or transfer of relays and switches, frequency shift in subcarrier oscillators, and transients induced in signal outputs. Usually, the design deficiency or workmanship problem is quite simple to correct. This characteristic may make the anomalies appear insignificant, especially in the development phase, and may partially explain the small number of reported problems.

TEST SIMULATION

The test firing of pyrotechnic systems may be performed for many reasons. For those interested in the shock environment, the pyrotechnic firing may be used as an equipment qualification test or may be the source of data from which individual equipment shock specifications may be derived. Individual equipment test specifications are implemented using a variety of simulation techniques, including conventional shock machines based on pulse shape reproduction, electrodynamic shakers controlled by synthesis/analysis hardware, and, to a lesser degree, airframe type test beds excited by explosive charges.

Full-scale qualification and flight acceptance tests of many NASA spacecraft are performed by detonation of the actual pyrotechnic devices in an installation incorporating actual structure. A margin of safety in number of stresses applied can be obtained by simply repeating the events as many times as desired. However, a margin of safety in shock amplitude is not achieved and, furthermore, repetition of some events, such as shroud separation, can be extremely expensive.

A ground test program was conducted to gain some insight into the degree of structural simulation required for full scale tests and to determine whether or not one could achieve a margin of safety by proper installation of the test hardware.

A test series was conducted on the following configurations:

A. Payload truss attached to Titan IIIC Transtage Skirt (Baseline Configuration);

B. Payload truss freely suspended;

C. Payload truss attached to rigid support fixture;

D. Payload truss attached to channel adapters (Adapters were designed to simulate the longitudinal stiffness of the payload skirt).

Photographs of the four configurations are shown in Fig. 2-5. Accelerometer locations on the payload truss are shown in Fig. 6. Examples of the average shock spectra obtained at locations 7 and 8 (satellite mounting points) for the four different configurations are shown in Fig. 7 and 8. Comparison of these data indicates that the use of the simple channel adapters to simulate the transtage skirt structure would provide a reasonable, conservative test of the satellite. The results, although inconclusive, are encouraging because they indicate that it may not be necessary to always include an expensive, complex structure in full scale testing.

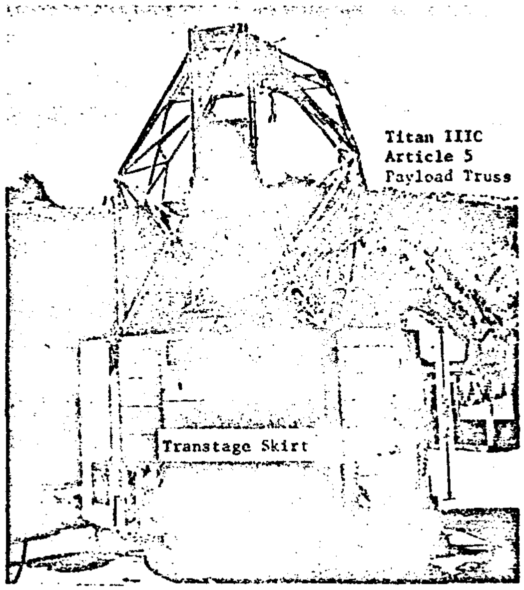

Fig. 2 - Test configuration I - payload truss installed on transtage skirt

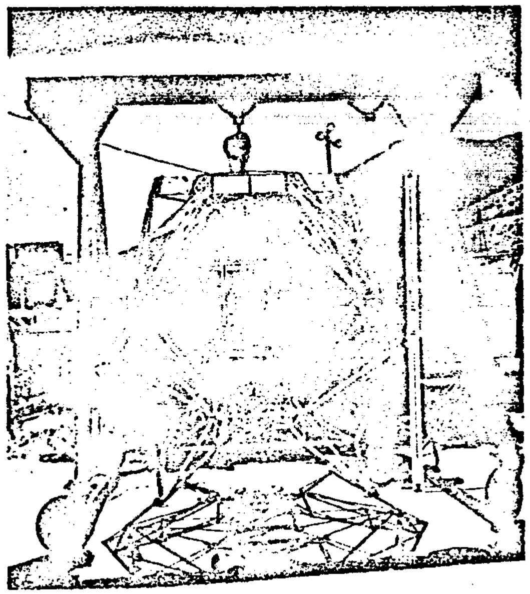

Fig. 3 - Test configuration II - payload truss freely suspended

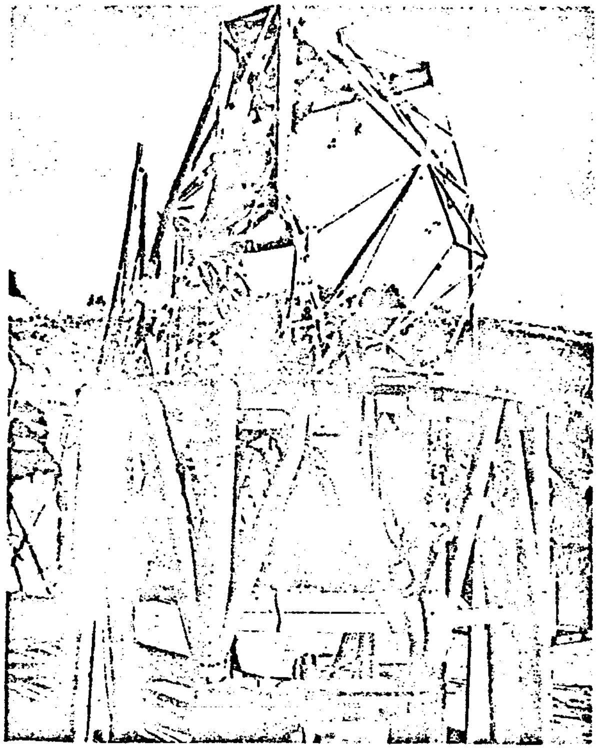

Fig. 4 - Test configuration III - payload truss attached to rigid support fixture

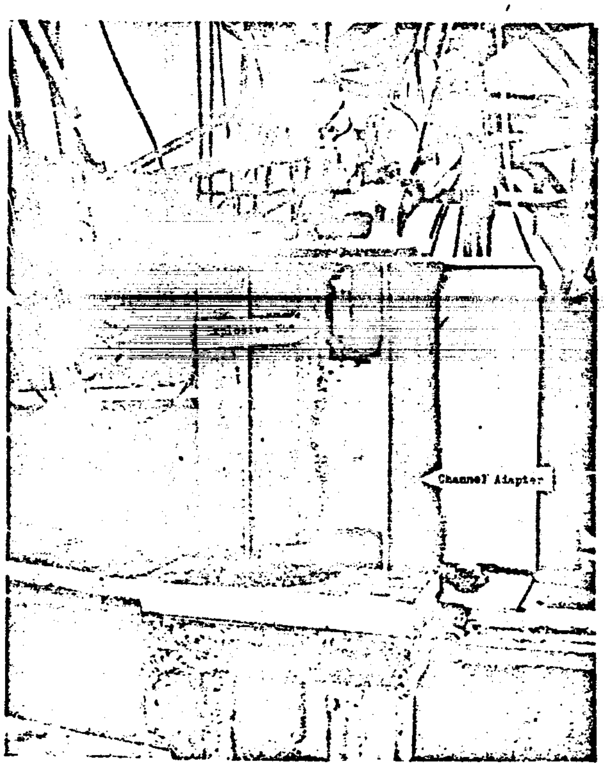

Fig. 5 - Test configuration IV - payload truss attached to channel adapters

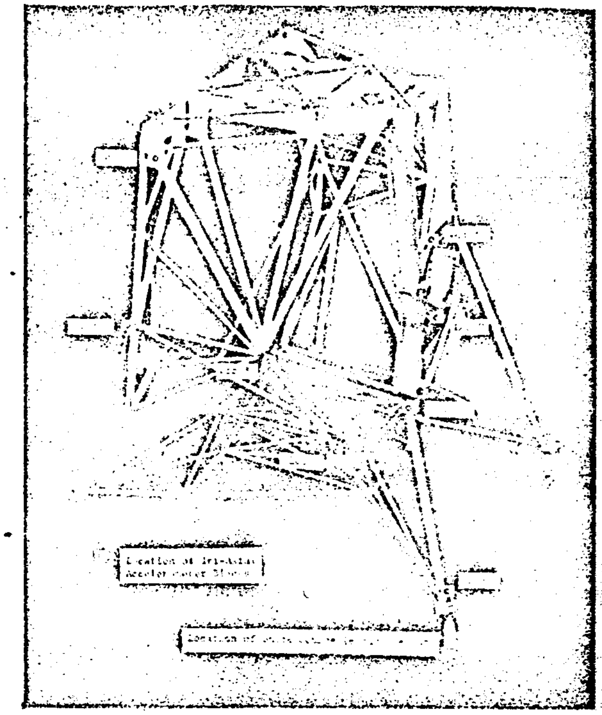

Fig. 6 - Payload truss and measurement locations

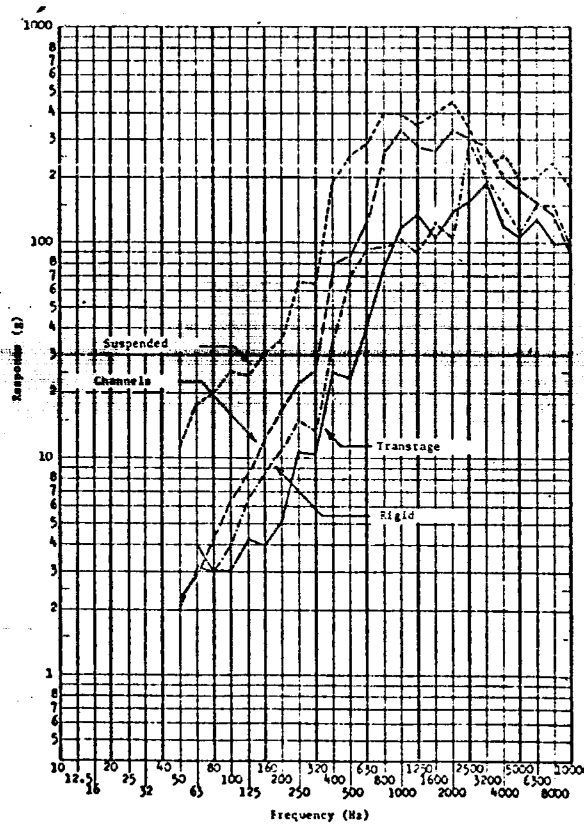

Fig. 7 - Shock spectra comparison for configurations at location 7, longitudinal axis

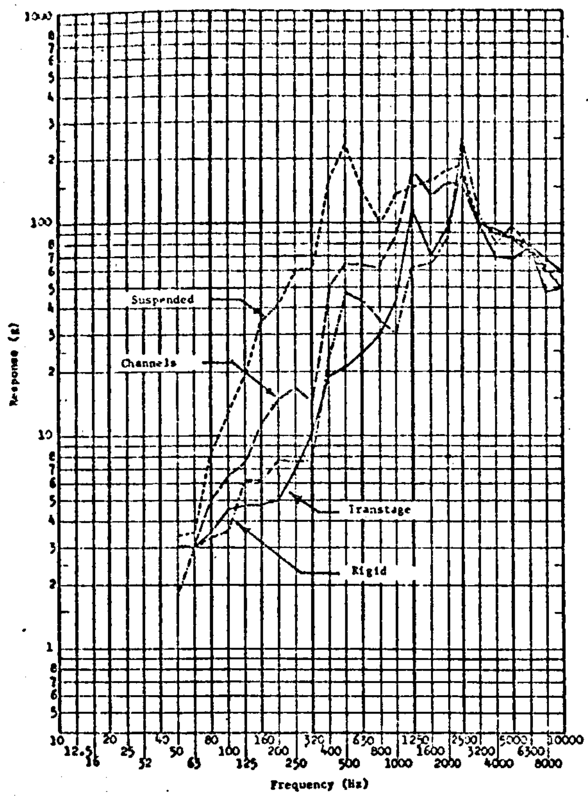

Fig. 8 - Shock spectra comparison for test configurations at location 8, longitudinal axis

MASS LOADING EFFECTS

A test and analysis program was conducted to determine the effect of weight variations in mounted subassemblies on the pyrotechnic shock environment. The effect, for both single and distributed mass loading, was evaluated at the interface of the subassembly and the mounting structure for two types of structures:

A. Airframe, skin and stringer construction;

B. Truss structure.

Final results of this study are not complete. However, preliminary results from the single mass loading tests are presented.

A full scale skirt and truss structure was used as the test fixture. Prototype components were installed on the airframe and on the truss as shown in Fig. 9 and high frequency accelerometers were installed in a triaxial configuration at component mounting points. Changes in weights of the two components were accomplished by the addition of small steel plates distributed throughout the equipment chassis (Fig. 10) to simulate electronic modules. A summary of the weight configurations tested is given in Table 2.

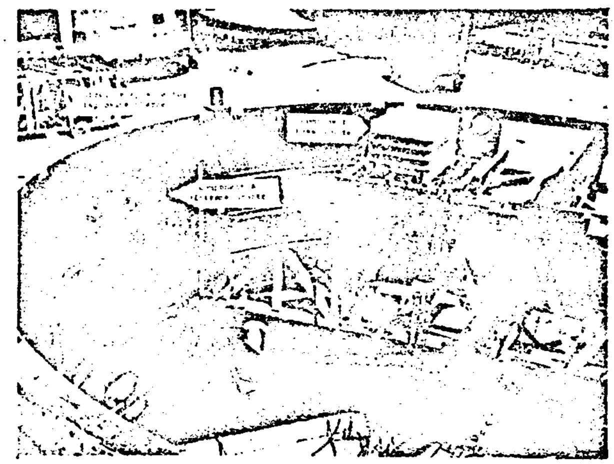

Fig. 9 - Locations of equipment installations and shock source

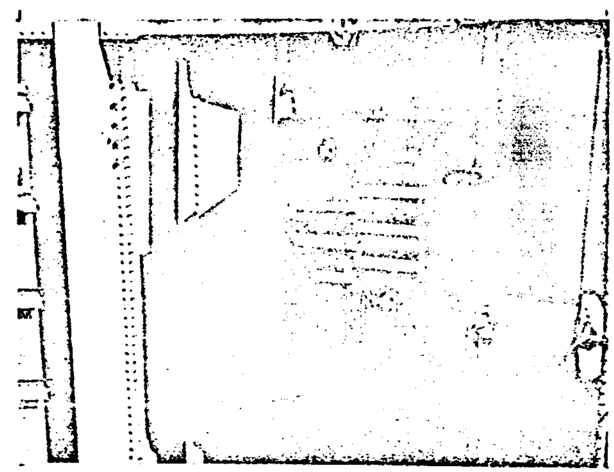

Fig. 10 - Component A showing installation of Weight

Table 2 Weight Configurations

	Component Weight (lb)	
	Component A Airframe Mounted	Component T Truss Mounted
Bare Structure*	0	0
Configuration 1	11.5	10.0
Configuration 2	23.0	20.0
Configuration 3	46.0	40.0

*Note: The total weight of the truss and skirt was 485 lb.

The pyrotechnic shock source consisted of a blasting cap and 50 grains of RDX explosive contained in a small plastic vial. The vial was inserted in a steel receptacle bolted to a longeron. This relatively inexpensive device produced excellent repeatability and provided an adequate simulation of typical data from ordnance devices used in the aerospace industry.

The tape recorded shock transients were digitized (100,000 samples/sec) and shock spectrum analyses were performed. The shock specrra were normalized to a reference accelerometer location and comparison plots made for the different weight configurations. An example of the results is shown in Fig. 11.

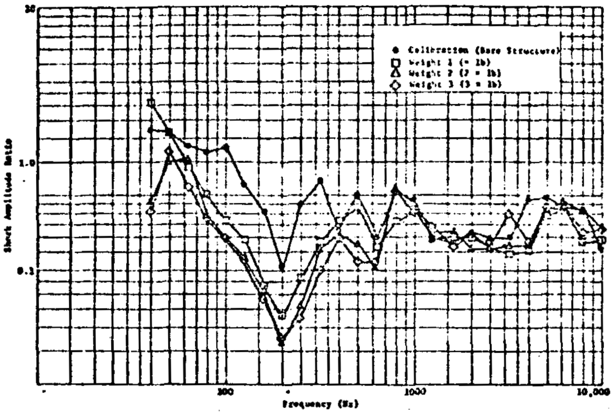

Fig. 11 - Comparison of normalized shock spectra for different component weights

The preliminary results of this study indicate that the primary effect on the shock environment occurs when an equipment item is installed on a previously unloaded structure. For the structure and component weights analyzed in this study, increasing the component weight by a factor of 2 or 4 has relatively little effect on the shock environment at the mounting point.

CONCLUSIONS AND RECOMMENDATIONS

The aerospace industry is presently using a variety of testing techniques to simulate pyrotechnic shock, most of which assume that duplication of the shock spectrum represents an adequate test. It is not clearly understood which parameters are related to damage potential. Additional efforts are needed to accumulate and disseminate failure information and to establish standardized methods for shock testing. Until such information is available it is recommended that the test methods used simulate the shock wave form as well as the shock spectrum. When this is impossible, the next alternative is matching the spectrum and the general character of the wave form; that is using a long duration, complex test for a long duration, complex environment.

From the preliminary results of this study it appears feasible to use relatively simple fixtures to simulate complex airframe structures in full scale tests. Additionally, it may be possible to obtain a test margin of safety for full-scale tests through proper design of such fixtures. Suggestions have been made to vary the amount of explosive charge or the tension in separation bolts to achieve a margin, but these techniques have not been proven.

The results of mass loading tests indicate that it is important to include prototype or "dummy" components in full scale tests if the correct pyrotechnic shock environment is to be achieved. However, after the components have been installed the effect of weight variations is relatively small and would not affect an established shock test specification. Final results from the mass loading effects study will be published in December 1970, as an addendum to Ref [1].

ACKNOWLEDGMENT

The total program briefly discussed in this paper had contributions too numerous to list here. Many individuals throughout the aerospace industry contributed data, correspondence, and discussions. The authors wish to express their gratitude for the cooperation and assistance provided by the individuals and the companies and agencies which they represent.

REFERENCES

1. W. J. Kacena, III, Dr. M. B. McGrath, and W. P. Rader, "Aerospace Systems Pyrotechnic Shock Data (Ground Test and Flight)," MCR-69-611. Martin Marietta Corporation, Denver, Colorado, March 7, 1970.

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Mr. Zell (Picatinny Arsenal): I think most of us feel that the shock spectrum is a pretty useful tool for giving a feel for the relative severity of different shock pulses of widely different character. But I wonder if perhaps the emphasis on presenting actual data, and in trying to analyze the data in terms of shock spectra has not actually created a clouding or an obfuscation that actually complicates analysis. If these data had not been in a Fourier spectrum type of presentation would not the effect of frequency on attenuation, or the effect of structural modes be much more easily analyzed? Perhaps the time has come when the shock spectrum should be used more as an engineering tool.

Mr. Rader: If I understand correctly — you are suggesting that the Fourier spectrum may give more basic engineering information than does the shock spectrum. Is that right?

Mr. Zell: Yes. The effects of frequency on attenuation and mode shapes might be more easily evaluated. In terms of analyzing what is actually happening, it seems that by having the data in terms of a shock spectrum, which is a method of looking at it through a certain type of colored glasses for convenience sake, this type of basic analysis actually clouds the issue rather than clarifies it.

Mr. Rader: During the course of this program one of the tasks was a comparison of Fourier spectra versus standard shock spectra. The Fourier spectra gave essentially no more information than the shock spectra for the complex waves that are generated by pyrotechnic shock devices. This is not true for simple pulses since the Fourier and the shock spectra can be quite different. But for the complex waves that one sees in typical pyrotechnic shock devices the Fourier and shock spectra yielded essentially the same information in our experience.

Mr. Zell: The various analysis methods for determining structural properties, such as mechanical impedance and transmissibility as a function of frequency, cannot be applied directly to a shock spectrum in data that is generally acquired in the course of a development and test program on a particular structure.

Mr. Rader: Yes, I think that is a good point. However, again as I mentioned in the introduction, the definition of, or even adequately explaining pyrotechnic shock analytically has just not been possible to date. Hopefully this will be a subject for future examination, perhaps the Fourier spectrum may be more useful to relate to structural parameters.

Mr. Smith (Bell Aerospace Corporation): Some time ago Bill Roberts did a more modest study suggesting that the shock spectrum showed an additional characteristic at the low frequency end which tended to be more of a constant displacement type of behavior, and I noticed that perhaps this was present in some of your curves. It is important I think to know where the constant velocity line is likely to become inapplicable at the low frequency end. Do you have a short observation on that?

Mr. McGrath: We were in correspondence with Bill Roberts and we looked for this characteristic of a constant displacement line at a very low frequency, but quite often the data confuses the issue at very low frequencies because of faulty techniques of obtaining the spectrum. We found that the constant acceleration lines, constant velocity lines, constant displacement, just did not lead to any definite results that we could see. The constant velocity lines that we are referring to are almost a subjective approximation in the low frequency range, which might go from approximately 100 Hz up to as high as a thousand Hz. This is what we observed. Someone else might observe something else, but it probably takes a specific type of a data reduction.

Mr. Smith: It seems to me that probably within all of these data there may be another important piece of data that is required; and that is, with respect to the various classifications of structure and distance from the source, to what sort of bounds on the mass would you expect to apply the acceleration data in attempting to apply this in a realistic design sense? Obviously one might be happy to apply some particular value of acceleration to a 2 pound mass under some circumstance and never dream of doing the same thing with a 100 pound mass. There is some boundary somewhere that I think might be developable from all this information. If I want to use your curves of acceleration against distance from some source, for how large an item or how heavy an item, are they applicable?

Mr. Rader: The curves presented by Dr. McGrath were developed on a number of different types of structures including spacecraft, booster skirt structure, complex truss structures and the like. So we feel that the curves are applicable for typical aerospace structures as they exist today. The effect of mass loading from the preliminary work which was shown here essentially has very little effect on the shock environment as shown in the last slide. Once the component is installed on the structure or on the truss, this constitutes the major effect on the shock environment. Changing that weight by a factor of 2 or 4 had practically no effect on the basic shock spectrum.